COMPOSITE MATERIAL PROGRESSING CAVITY STATORS

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FIELD OF THE INVENTION

[0001] The present invention relates generally to progressing cavity hydraulic drilling motors, typically for downhole use. This invention more specifically relates to fiber reinforced composite stators and methods for fabricating fiber reinforced composite stators.

BACKGROUND OF THE INVENTION

[0002] Progressing cavity hydraulic motors and/or pumps are well known in downhole drilling and artificial lift applications, such as for oil and/or gas exploration. Such progressing cavity motors make use of hydraulic power from drilling fluid to provide power, for example, to a drill bit assembly. The power section of a typical progressing cavity motor includes a helical rotor disposed within the cavity of a corresponding stator and converts the hydraulic power of high pressure drilling fluid to mechanical power (e.g., torque). Flow of the high pressure drilling fluid down through the rotor stator assembly rotates the rotor relative to the stator (which is usually connected to a motor housing). The rotor is typically coupled, for example, through a universal connection and an output shaft to a drill bit assembly.

[0003] Conventional stators typically include an elastomeric (e.g., rubber) contact surface bonded to the inner wall of a steel housing. In order to form a progressing cavity, the elastomer is typically thicker at the peaks of the helicoid. It has been observed that working (i.e., flexing) of the elastomer (via rotational contact between the rotor and stator) during operation causes degradation thereof, particularly at thick regions at the peaks of the helicoid. It is thought that such degradation results from heat build up in the elastomer (due to the relatively low thermal conductivity of elastomeric materials). The thicker regions are believed to attain relatively higher temperatures than thinner regions of the helicoids, and are hence more prone to degradation and failure. Such degradation (or weakening) of the elastomer is known to damage the seal between the rotor and stator and eventually to cause failure of the stator. As a result, such degradation tends to reduce the life of the stator and necessitate replacement thereof at undue frequency and cost.

[0004] U.S. Patent 6,183,226 to Wood et al. (hereafter referred to as the Wood patent) discloses a stator including areas of composite material, which are intended to act as a supportive structure for the helicoid interface of a rubber elastomer. The Wood patent discloses a filament winding process for forming the composite material, which results in the composite fibers being substantially aligned with the helical grooves along the length of the stator. Such aligning of the fibers likely increases the internal stress in the composite material and thereby reduces its overall strength. Further, such aligning of the fibers likely results in anisotropic mechanical properties, i.e., a relatively high strength along the length of the fibers and a relatively low strength in transverse directions. Therefore, there exists a need for improved composite design for progressing cavity stators and improved methods of fabricating such composite stators.

SUMMARY OF THE INVENTION

[0005] The present invention addresses one or more of the above-described drawbacks of prior art progressing cavity motors and/or pumps. Referring briefly to the accompanying figures, aspects of this invention include a progressing cavity stator for use in a progressing cavity motor, such as in a downhole drilling assembly. The progressing cavity stator includes a fiber reinforced composite component having a plurality of helical lobes disposed along the inner surface thereof. The composite component includes a plurality of fibers disposed in a matrix material, such as a theremosetting resin. The fibers are disposed in the composite component such that distinct portions of the fibers follow correspondingly distinct directions, which may be advantageously intertwined. In alternate embodiments, this invention includes a progressing cavity composite insert for use in a progressing cavity stator. Methods for fabricating progressing cavity stators and progressing cavity composite inserts are also provided.

[0006] Exemplary embodiments of the present invention advantageously provide several technical advantages. Various embodiments of the progressing cavity stator of this invention may exhibit a prolonged service life as compared to conventional progressing cavity stators. Tools embodying this invention may thus display improved reliability and thereby provide for potentially significant cost savings. Various embodiments of the fabrication procedure may also provide for the fabrication of a replaceable composite stator insert. Such a composite stator insert advantageously promotes field service flexibility. For example, damaged inserts may be replaced in the field at considerable savings of time and expense. Alternatively, an existing insert may

be changed to one having, for example, a different number of lobes to optimize power section performance to current needs (e.g., with respect to speed and power).

[0007] In one aspect this invention includes a method for fabricating a progressing cavity stator. The method includes providing a first core having at least one helical groove on an outer surface thereof and disposing a plurality of fibers in each helical groove to form a fiber preform. The method also includes inserting the fiber preform into a cylindrical tube, injecting a resin into the cylindrical tube to form an impregnated fiber preform, and removing the first core from the impregnated fiber preform thereby forming an internal helical cavity in the impregnated fiber preform. The method further includes inserting a second core, having at least one helical groove on an outer surface thereof, into the internal helical cavity of the impregnated fiber preform, the second core having a smaller diameter than that of the first core, thereby forming a substantially helical annulus between the second core and the impregnated fiber preform, injecting an elastomeric material into the helical annulus, and removing the second core.

[0008] In another aspect this invention includes a progressing cavity stator including a fiber reinforced composite component that provides an internal helical cavity having at least one helical groove and an elastomeric liner disposed on an internal surface of the composite component. In certain exemplary embodiments, the fiber reinforced composite component includes a plurality of fibers disposed in a matrix material, the plurality of fibers disposed such that distinct portions thereof follow correspondingly distinct directions. In other exemplary embodiments, the elastomeric liner includes a non-uniform thickness, the non-uniform thickness varying in directions of at least one of parallel to a cylindrical axis of the stator and radially about the cylindrical axis of the

stator. In still other exemplary embodiments, the combination of the fiber reinforced composite component and the elastomeric liner form a replaceable progressing cavity insert, of which the outer surface is sized and shaped for removable receipt within a cylindrical tube.

[0009] The foregoing has outlined rather broadly the features and technical advantages of the present invention in order that the detailed description of the invention that follows may be better understood. Additional features and advantages of the invention will be described hereinafter which form the subject of the claims of the invention. It should be appreciated by those skilled in the art that the conception and the specific embodiment disclosed may be readily utilized as a basis for modifying or designing other structures for carrying out the same purposes of the present invention. It should also be realize by those skilled in the art that such equivalent constructions do not depart from the spirit and scope of the invention as set forth in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] For a more complete understanding of the present invention, and the advantages thereof, reference is now made to the following descriptions taken in conjunction with the accompanying drawings, in which:

[0011] FIGURE 1 is a schematic representation of an offshore oil and/or gas drilling platform utilizing an exemplary embodiment of the present invention.

[0012] FIGURE 2 depicts a progressing cavity motor utilizing an exemplary embodiment of the present invention.

[0013] FIGURE 3 is a cross sectional view of one exemplary embodiment of a progressing cavity stator according to this invention.

[0014] FIGURE 4 is a cross sectional view as shown on FIGURE 3.

[0015] FIGURE 5, is a cross sectional view of another exemplary embodiment of a progressing cavity stator according to this invention.

[0016] FIGURE 6 is a perspective, cut-away view of an exemplary embodiment of a fiber preform used in the fabrication of various embodiments of this invention.

[0017] FIGURE 7 depicts one exemplary arrangement used in the fabrication of various embodiments of this invention.

[0018] FIGURE 8 is a cross sectional view of another arrangement used in the fabrication of various embodiments of this invention.

[0019] FIGURE 9 is a cross sectional view of yet another exemplary embodiment of a progressing cavity stator according to this invention.

[0020] FIGURE 10 is a cross sectional view of still another exemplary embodiment of a progressing cavity stator according to this invention.

DETAILED DESCRIPTION

[0021] FIGURES 1 and 2 illustrate one exemplary embodiment of a progressing cavity stator 100 according to this invention in use in an offshore oil or gas drilling assembly, generally denoted 10 on FIGURE 1. In FIGURE 1, a semisubmersible drilling platform 12 is positioned over an oil or gas formation (not shown) disposed below the sea floor 16. A subsea conduit 18 extends from deck 20 of platform 12 to a wellhead installation 22. The platform may include a derrick 26 and a hoisting apparatus 28 for raising and lowering the drill string 30, which, as shown, extends into borehole 40 and includes a progressing cavity motor 50 coupled to a drill bit assembly 52. In FIGURE 2, the progressing cavity motor 50 includes a rotor 56 operational within a progressing cavity stator 100. As described in more detail below, the stator 100 includes a fiber reinforced composite component.

[0022] It will be understood by those of ordinary skill in the art that the progressing cavity stator 100 of the present invention is not limited to use with a semisubmersible platform 12 as illustrated in FIGURE 1. Progressing cavity stator 100 is equally well suited for use with any kind of subterranean drilling and/or pumping operation, either offshore or onshore. It will also be understood that the progressing cavity stator of this invention is not limited to downhole applications, but may be utilized in substantially any application in which progressing cavity hydraulic motors and/or pumps are used.

[0023] With reference now to FIGURES 3 and 4, one exemplary embodiment of the progressing cavity stator 100 of this invention includes an outer cylindrical member 102 (such as a steel tube), which is typically couplable to a drill string when used for downhole applications, an inner elastomeric layer 104, and a fiber reinforced composite

component 110 interposed between the cylindrical member 102 and the elastomeric layer 104. The fiber reinforced composite component 110 is shaped to define a plurality of helical lobes 112 and grooves 114 on an inner surface 116 thereof. The fiber reinforced composite component 110 includes a plurality of fibers disposed in a matrix material, such as a theremosetting resin. The fibers are disposed in the composite component 110 such that distinct portions of the fibers follow correspondingly distinct directions. In certain embodiments, distinct portions of the fibers may be advantageously intertwined. The fibers may have substantially any suitable configuration, such as fiber roving, woven and/or non-woven fibers, braided fibers, fiber bundles, fiber bundles wrapped in a braided fiber sock, stitched three-dimensional fabrics, combinations thereof, and the like. The use of woven and/or braided fibers may be preferable for some embodiments since such fiber configurations include distinct intertwined fibers and/or fiber bundles that follow correspondingly distinct directions. The use of such fiber configurations also tends to result in a composite component having somewhat isotropic mechanical properties, especially as compared to a composite component in which the fibers are substantially aligned in one direction (such as that formed in a typical filament winding process, for example, as described in the Wood patent).

[0024] With further reference to FIGURES 3 and 4, it will be appreciated that the composite component 110 may include short strand fibers (e.g., chopped fibers). Such short strand fibers may be blended, for example, with a suitable resin material and injected into the lobe regions of the stator. Such a fabrication procedure may include molding the composite component according to known molding techniques and may advantageously result in a composite having substantially isotropic mechanical properties.

In such embodiments it will be appreciated that the short strand fibers, as dispersed in a matrix, are typically oriented in substantially random directions so as to encourage isotropy.

[0025] With further reference to FIGURES 3 and 4, embodiments of the composite component 110 may be fabricated from substantially any fiber and matrix materials that are stable under downhole conditions (e.g., up to about 200 degrees C or more). For example, desirable fibers may include glass fibers, carbon fibers, aramid fibers, boron fibers, polyester fibers, polyethylene fibers, combinations thereof, and the like. The matrix material is typically formed from a combination of a thermosetting resin, such as DER 331 epoxy resin, available from Dow Chemical Company, Midland, MI or EPON 826 epoxy resin available from Resolution Performance Products, and a hardener (or curing agent) such as Amicure® PACM available from Air Products, Allentown, PA. It will be appreciated by those skilled in the art that various optional modifiers and/or additives may be added to the epoxy resin hardener blend. In a typical desirable embodiment, the composite material includes various braided glass fibers disposed in an epoxy resin matrix.

[0026] Referring now to FIGURE 5, certain embodiments of the progressing cavity stator 100' of this invention include a composite stator insert 120 that is removable from an outer cylindrical member 102' as shown at 131. In the event of elastomeric degradation, for example, the composite stator insert 120 may be replaced in the field (e.g., at a drilling rig) typically providing significant savings in time and expense. The composite stator insert 120 (also referred to as a replaceable composite stator) is similar to progressing cavity stator 100 on FIGURES 3 and 4 in that it includes an elastomeric

layer 104 disposed on an inner surface of a composite component 110', which defines a plurality of internal helical lobes 112 and grooves 114 as described above. The composite stator insert 120 is coupleable to an outer cylindrical member 102', for example, via a groove 122A and corresponding key 122B machined into the composite component 110' and cylindrical member 102', respectively. The composite stator insert 120 may alternatively (or additionally) be coupled to outer cylindrical member 102' via a snap ring 124B and corresponding groove 124A deployed on the insert 120 and cylindrical member 102', respectively. It will be recognized that composite stator insert 120 may also be coupled to cylindrical member 102' by substantially other suitable arrangements, such as, for example, by clamping, bonding via various adhesives, or press fitting.

[0027] With continued reference to FIGURES 3 and 4 and further reference to FIGURES 6 through 8, exemplary methods for fabricating various embodiments of the composite stator of this invention are described. FIGURE 6 depicts, in cut away view, a fiber preform 150 used in the fabrication of a composite stator. A substantially cylindrical core 152 is prepared (e.g., fabricated from a metallic material such as a conventional carbon steel having a smooth surface finish). It will be appreciated that the core 152 may be substantially solid (e.g., formed from a solid bar) or include a hollow interior along its longitudinal axis 155 (e.g., formed from a tube). The core 152 includes at least one helical lobe 162 and corresponding helical groove 164 formed in the outer wall 154 thereof. It will be appreciated that the core 152 may include substantially any suitable number of helical lobes 162 and grooves 164 depending upon the requirements of the stator. Typical stators include from 2 to about 10 or more helical lobes and

corresponding grooves, although the invention is not limited in this regard. Various fibers are disposed in the helical grooves 164 and around the outer wall 154 of the core 152. For example, in the exemplary fiber preform 150 shown on FIGURE 6, a braided fiber layer 172 is disposed about the core 152. The helical grooves 164 of the core 152 are then partially or fully filled with one or more braided fiber tubes (or ropes) 174. The braided fiber tubes 174 may be secured in place (i.e., in the helical grooves 164), for example, via circumferential fiber windings 176 and a second braided fiber layer 178. Depending upon the depth of the helical lobes 164 and the diameter of the braided fiber tubes 174, the fiber preform 150 may include several repeating layers of braided fiber tubes 174, circumferential fiber windings 176, and braided fiber layers 178. Fibers are typically applied to the fiber preform 150 until the helical grooves 164 have been substantially filled and/or until the fiber preform 150 attains some predetermined thickness. Alternatively, a custom braided fiber strand having a profile (cross section) similar to that of the helical grooves in the core may be utilized. Such a custom braided fiber rope may be advantageous in that the helical groove in the core (e.g., groove 164 in core 152) will be effectively completely filled with fiber material. In another alternative embodiment, an impregnated fiber composite strand having a profile similar to that of the helical groove may be utilized. Such a fiber composite strand may be formed, for example, via a conventional pultrusion process in which impregnated fibers are pulled through a heated die.

[0028] With continued reference to FIGURES 6 through 8, the fiber preform 150 may be inserted into a steel tube 180 (e.g., cylindrical member 102 in FIGURE 3). In one exemplary fabrication method shown in FIGURE 7, the ends of the tube are sealed with

appropriate end fittings 182 and 183 having various ports 184 and 185 disposed therein. A liquid thermosetting resin, such as Dow Chemical DER 331 epoxy resin, is injected into the tube 180, for example, via port 185, to substantially impregnate the fibers and displace any air in the tube 180. The artisan of ordinary skill will readily recognize that substantially any suitable injection method may be utilized, such as conventional resin transfer molding and/or various known vacuum molding techniques (e.g., by evacuating the tube 180 at port 185). Vacuum techniques are typically desirable, as they tend to promote air displacement. Upon completion of the injection procedure, the ports 184 and 185 are sealed and the tube 180 may be heated to cure the resin. Such impregnation of the fibers and subsequent curing results in a solid fiber reinforced composite material. After curing of the resin, the core 152 (FIGURE 6) is extracted from the fiber reinforced composite material resulting in a composite component having an internal helicoid cavity (e.g., composite component 110 on FIGURES 3 and 4). The core 152 may be treated with a mold release, such as honey wax mold release, to promote such extraction.

[0029] After removal of the core 152 (FIGURE 6), the inner surface 116' of the composite component 110' (FIGURE 8) may be prepared by one of numerous techniques, including cleaning with various solvents and/or metal blasting and/or abrading techniques. Such preparation of the inner surface 116' of the composite component 110" is intended to promote adhesion of an elastomeric material to the composite component 110". A second core 192, having a smaller outer diameter than core 152, is then inserted substantially coaxially into the cavity of the composite component 110". An elastomeric material (e.g., rubber) is injected into the helical annulus 194 between the second core 192 and the composite component 110'. After curing of the elastomeric material, the

second core 192 is removed from the stator, which is subsequently ready for final machining or other finishing operations (if required). The second core 192 may also be treated with a mold release to promote such extraction.

[0030] With continued reference to FIGURES 6 through 8, a similar procedure may be utilized to fabricate a composite stator insert (such as composite stator insert 120 shown in FIGURE 5). A fiber preform may be formed and impregnated as described above with respect to FIGURES 6 and 7. The impregnated fiber preform (e.g., fiber preform 150 after resin impregnation) is removed from tube 180 after curing of the resin. This may be accomplished, for example, by treating the inner surface of the tube 180 with mold release to substantially prevent the impregnated fiber preform from bonding to the tube 180. The interior surface of the impregnated fiber preform may then be prepared and an elastomeric layer disposed thereon, for example, as described above with respect to FIGURE 8. Alternatively, the impregnated fiber preform may be removed from tube 180 after injection and curing of the elastomeric layer. After removal from the tube 180, the outer surface of the impregnated fiber preform may be machined, for example, to form a key (e.g., groove 122A shown on FIGURE 5) and/or for final sizing and shaping (e.g., to accommodate press fitting of the insert into a stator tube).

[0031] Turning now to FIGURE 9, another exemplary embodiment of a progressing cavity stator 200 is shown. Stator 200 is similar to stator 100 shown in FIGURES 3 and 4, in that it includes a fiber reinforced composite component 210 interposed between an inner elastomeric layer 204 and an outer cylindrical member 102. Stator 200 differs from stator 100 in that the composite component 210 and the elastomeric layer 204 are tapered along the longitudinal axis 205 of the stator 200. In the embodiment shown on FIGURE

9, the radial thickness 222 of elastomeric layer 204 increases from the top 201 to the bottom 202 of the stator 200, while the radial thickness 224 of the composite component 210 (e.g., at lobes 212) decreases from the top 201 to the bottom 202 of the stator 200, such that internal radial dimensions 226 and 228 remain unchanged along the longitudinal axis 205 of the stator 200. It will be appreciated that stator composite component 210 and the elastomeric layer 204 may include substantially any taper and that internal radial dimensions 226 and 228 may also vary along the longitudinal axis. For example, radial thicknesses 222 and 224 may increase together along the longitudinal axis 205 from the top 201 to the bottom 202 of the stator 200. Alternatively, the radial thickness 222 of the elastomeric layer 204 may vary along the longitudinal axis 205, while that of the composite component 210 remains substantially unchanged. Terms used in this disclosure, such as “top” and “bottom”, are intended merely to show relative positional relationships of various components and are not limiting of the invention in any way.

[0032] With continued reference to FIGURE 9, stator 200 may be advantageous for various downhole drilling applications in that having a relatively thicker elastomeric layer 204 at the bottom 202 of the stator 200 provides increased flexibility to absorb loads induced by the eccentric path of the rotor while having a relatively thinner elastomeric layer 204 at the top 201 of the stator 200 increases rigidity and therefore increasing the output torque of the progressing cavity motor.

[0033] With reference now to FIGURE 10, still another exemplary embodiment of a progressing cavity stator 300 is shown. Stator 300 is similar to stator 100 shown in FIGURES 3 and 4, in that it includes a fiber reinforced composite component 310 interposed between an inner elastomeric layer 304 and an outer cylindrical member 102.

Stator 300 differs from stator 100 in that the radial thickness 322 of the elastomeric layer 304 varies circumferentially about the stator 300. Such a variation in the radial thickness 322 may advantageously be periodic (e.g., radially symmetric about a cylindrical axis (not shown in FIGURE 10) of the stator). The composite lobes 312 may be shaped to accommodate the varying radial thickness 322 of the elastomeric layer such that the shape of the internal cavity 305 in stator 300 is substantially identical to that of the internal cavity of stator 100. Alternatively, the second core 192 (FIGURE 8) may be skewed slightly with respect to the impregnated fiber preform thereby resulting in the formation of an uneven elastomer layer around each lobe of the composite. Stator 300 may be advantageous for certain applications in that regions of the stator that are subject to higher stresses (e.g., the leading edge of the lobes) may include a relatively thicker elastomeric layer.

[0034] Progressing cavity stators 200 and 300 may be fabricated using a similar procedure to that described above with respect to FIGURES 6 through 8. In the fabrication of embodiments of stator 100 (using the procedure described above with respect to FIGURES 6 through 8) the first 152 and second 192 cores have substantially the same profiles (i.e., the shape of the lobes and grooves are substantially the same). The primary difference between the two cores is that the second core 192 has a smaller diameter than the first core 152. Thus the thickness of the elastomeric layer 104 (FIGURES 3 and 4) is substantially uniform and substantially equal to the difference between the two diameters. In such a manufacturing procedure, the use of cores having different profiles generally results in an elastomeric layer with a non-uniform thickness. For example, stator 200 may be fabricated using a tapered first core (i.e., a core in which

the outer diameter increases from one end to the other). Such a tapered core results in a composite component having a tapered inner diameter. The use of a second core having a uniform outer diameter then results in a stator in which the thickness of the elastomeric layer increases along the cylindrical axis. Similarly stator 300 may be fabricated, for example, using a first core in which the shapes of the lobes and/or grooves differ from that of the second core. The artisan of ordinary skill will readily recognize that the above described procedure advantageously permits fabrication of stators having substantially any variation in the thickness of the elastomeric layer and/or the composite component.

[0035] Although the present invention and its advantages have been described in detail, it should be understood that various changes, substitutions and alternations can be made herein without departing from the spirit and scope of the invention as defined by the appended claims.